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# WATER PURIFICATION,

## HYGIENICALLY CONSIDERED.

BY

C. GILMAN CURRIER, M.D.,

ASSOC. AM. SOC. CIV. ENG.

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# WATER PURIFICATION HYGIENICALLY CONSIDERED.

BY C. G. CURRIER, M.D.,
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A FEW years ago the author, in various articles giving the results of experimental investigations on some of the subjects touched upon in these pages, felt bound to offer considerable evidence to prove that pure water is necessary to health, and that thousands of lives are yearly lost because of impure water.[1] Many epidemics due to a bad water supply have been reported at more or less length in the medical journals and in the daily papers, which reach all classes. Thousands or even hundreds of thousands of deaths from cholera have occurred in Asia, in the Orient, in Egypt, and in Europe. The recent epidemic in Hamburg (1892) is still vividly impressed upon the minds of those who give any thought to the question of water-borne diseases.

Fortunately the broad oceans safeguard us to a large extent against cholera and other Asiatic plagues; but here, as well as elsewhere, typhoid fever, not to speak of various lesser diarrheal disorders which are likewise communicated by impure drinking-waters, yearly causes thousands of deaths and many more cases of disease of varying degrees of severity. Even malaria is regarded by numerous intelligent physicians and other acute observers as presumably a

[1] During the last few years there has been furnished so much statistic and other testimony to this effect that it would require too much space to reproduce it here.

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water-borne disease, although the evidence offered does not suffice to prove that contention. Yet typhoid fever alone is a sufficiently grave peril to warrant an immense amount of agitation and the expenditure of many millions of money to prevent its occurrence. It is very well known that when the water-supply of any isolated household or of any community is naturally pure or adequately purified by artificial means, typhoid fever does not occur unless water be casually consumed from an impure source, or unless milk or other food, used in an uncooked condition, have come in contact with infected water, or unless the victims have acquired the disease directly from someone suffering from it. For all industrial and domestic purposes it is desirable that water be as pure as possible. Whether for "feeding" a boiler or quenching thirst, for watering the streets or cleansing a wound, the purest water is the most satisfactory. The enlightened economist and the sanitarian insist upon this, and, even if space permitted, a citation of the volumes of facts and figures available to prove it would not be necessary for those familiar with the rudiments of modern sanitation.

What then is pure water, hygienically speaking? Briefly, it may be said to be clear, palatable, free from bacteria in large numbers, and wholly free from bacteria which can cause disease; it must contain no lead or other poisons, and have only a permissibly small amount of mineral salts. The salts of lime and magnesia, in a supply for general industrial and domestic use, must not be much in excess of 15 parts in 100,000 of water, otherwise it is too hard. The water of the best lakes and rivers may be less than one-half

or even one-fourth as "hard" as this. It should be mentioned that the salts present in the water which we drink do not count for much in the total amount needed daily by the human body (nearly two ounces of salts being required), as that amount is abundantly supplied by a mixed diet. The daily amount of water swallowed by a healthy man averages about a gallon. This quantity of good natural water usually does not contain more than ten grains of salts, and a mineral water having one hundred grains of salts to the gallon is altogether too strong for large amounts of it to be tolerated. A slight proportion of lime is hygienically desirable in water-supplies, for it restricts the tendency of the water to act upon metals. A very soft water more readily takes up lead, for instance, from lead pipes in which it is conveyed. A very soft moorland water, especially if acid and well oxygenated, is more apt to cause lead-poisoning to develop than is the case with limy waters.

Clearness, to the uninstructed, seems to be the most important quality of a water, and yet the clearest water, particularly that of wells, often causes typhoid fever, for the causative bacteria of that disease are not detectable by the senses when they have been introduced into a supply. On the other hand, turbidity is not usually due to a dangerous cause, however unpleasant it may appear to the eye. Water may be perfectly wholesome, and yet so colored by harmless vegetable matter as to arouse distrust among those unfamiliar with it. Chemic tests of water are of most importance nowadays as aiding one to determine its mineral constituents. In studying a proposed new supply, especially if it be from a peaty

source, it is well to know its degree of solvent action upon lead, for it is quite expensive to construct and maintain the plant needed for counteracting such a tendency, by filtration through lime or by the suitable addition of lime or soda carbonates. Of the organic constituents, an undue quantity (more than .015 in 100,000 parts) of albuminoid ammonia is the important practical factor which aids us to determine whether a water is bad or not. Wanklyn, in his latest work on "Water Analysis," does not attach much importance to the presence of nitrates, although they are usually regarded as evidence against the purity of a water. The elaborate organic chemic testing of a sample of water is not of nearly as much hygienic value as a careful local inspection by a skilled hydrologist of the sources whence the water comes and a critical searching for possibilities of present or future contamination.

Chemistry, then, being an inadequate guide, except as regards the presence of metals and salts, can any degree of reliance be placed upon the revelations of the microscope as to whether a water contains or is likely to contain matters or organisms prejudicial to health? Not to any sufficient extent. Of course, if tapeworm eggs or partially digested meat fibers be detected in a sample of water, it evidently is polluted, and must be condemned; but it is hardly probable that such things, even if present, will be found to have come into the exceedingly small field of a microscope. Nor does the recognition of protozoa in water aid us hygienically, according to Neisser, who has made a special study of this subject. While a water rich in organic matter is likely

to contain many micro-organisms, it may not have many protozoa. On the other hand, both bacteria and protozoa can thrive in water that is very pure indeed. Wash-water, sewage, privy-vaults, and manure-heaps are rather lacking in protozoa, although affording most unwholesome contaminations of drinking-water. Every leaf or blade of grass that falls into a well introduces more protozoa (*monadines, amebæ, ciliata*) than would human feces. Protozoa abound in hydrant water at all seasons.

During the last fifteen years an incontrovertible mass of evidence has accumulated to prove that when drinking-water causes cholera, typhoid fever, and other diseases it is because of the presence in the water of the bacteria peculiar to that disease. While heretofore none of the various methods in use have enabled us to always recognize with certainty the disease-producing bacteria which are present among the numerous microbes of harmless character always to be found in ordinary water, it seems as though we are on the threshold of important discoveries in this direction. Even the familiar gelatin-culture method is of considerable value in the service of an expert, although local inspection is always of paramount importance.

The usual way to make the gelatin test is to add some of the water to strong, specially prepared, sterile bouillon made solid by the addition of gelatin, as explained in THE MEDICAL NEWS by the writer (April 27, 1889). This is done carefully after the gelatin is softened by gentle heat. Then the gelatin is allowed to "set," and in two days, more or less, the isolated bacteria of the original drop or

more of water added, being diffused evenly throughout the mass of nutrient gelatin, will have increased enormously in that favorable medium. Accordingly, each separate one of the bacteria ($\frac{1}{10000}$ of an inch in size), although of itself visible only by the aid of high powers of the microscope, has, by multiplying to millions, formed a visible dot, cup, or other peculiar appearance separate from the others.

Without taking the necessary space to explain the many details of bacteriologic work which do not bear directly upon the subject of this paper, it may be briefly stated that, after years of discussion of the value of the mere counting of the number of bacteria present in a cubic centimeter of a carefully taken fresh sample of water, as a rule a water which has few bacteria is better than one which has many. The best waters have usually less than one hundred bacteria in each cubic centimeter (nearly one-fourth of a teaspoonful). Yet a large number of the organisms should not necessarily be considered as indicating that the water is unfit for use; and, on the other hand, disease bacteria entering a water which normally has few bacteria may produce serious infection. Of course, the species of bacteria present must be considered in forming an opinion. Elsner's method, consisting in using "potato gelatin" containing one per cent. of iodid of potash, promises to aid materially in the recognition of typhoid germs in water. For testing the efficacy of filters or other means of rendering an infected water fit to drink, the gelatin-culture test is all-important. It is the bacteria in such a water that the sanitarian regards as the element of danger. If the process removes all of these,

it effectually purifies the water; and if it removes or destroys all but a minute proportion of these micro-organisms, it is safe to assume that practically all of the disease-producing germs, if any were present, have been removed. That the water produced is clear or palatable is, of course, readily determined by the senses.

In testing a filter in operation, the original water is examined from time to time by collecting average samples in heat-sterilized bottles. A cubic centimeter, or half as much, of a sample is taken in a sterile glass pipette and added to a cotton-plugged test-tube containing ten cubic centimeters of nutrient gelatin which has been softened by gentle warmth. After these are commingled the gelatin is poured upon a cool plate of sterile glass or a flat glass dish, and this is then promptly covered and labeled. Another test-tube of gelatin is treated in the same way, but is plugged with its sterile cotton as soon as the water is added. After mixing this in by gentle agitation, it is marked and laid upon its side so that the fluid gelatin and water reaches almost up to the cotton. Frequent samples of the filtered water are taken with care to prevent the entrance of bacteria from without. These are plated and tubed in the way just indicated, and all the plates and tubes are then kept away from dust and strong light, under identical conditions of free air, light, and moisture. Those in which the water introduced was sterile will show the gelatin unchanged even after a week, while those into which bacteria entered with the water will show a varying number of colonies corresponding to the number of bacteria entering. Usually those from

filter-samples are of fewer varieties, even if—as in the case of low-grade or badly cared-for filters—greater in number than with the same amount of water from the raw supply.

Natural purification by slow flow through many feet of fine, porous earth produces water absolutely free from harmful or other bacteria which may have been in the water or on the surface where it fell. The majority of investigators find that, while bacteria abound on and very near the surface, they are greatly lessened a yard beneath the surface of the ground, and five or six feet deeper, in fine soil, none of these have penetrated. Accordingly, such ground-water, whether issuing as uncontaminated natural springs, or even obtained by properly constructed and protected wells, is very pure as regards bacteria, although it may have taken up a considerable amount of mineral matter. Water evaporated from oceans, lakes, and the top of the ground, and precipitated as rain, is then, like distilled water, very soft and pure, although that which first falls takes up some impurities from the air, especially near cities and from the roofs from which it is collected. In very many examinations made in various parts of this country the author, like others, has regularly found that brooklets in unsettled regions have very few bacteria, and that larger streams and lakes supplied by springs and rainfall from watersheds which are uninhabited and untilled have, as a rule, few bacteria. But as human habitations and industries increase, the number of bacteria present also increases, and a river in an agricultural valley, even without sewage entering the stream, has many more bacteria than a similar one

in an uncultivated district under the same conditions of rainfall.

Communities which derive an abundant supply from the best of such upland sources, and which can preserve the watershed free from all permanent or temporary human contamination, have an ideal water-supply. Unfortunately, such pure supplies are altogether too few and do not increase, while the demand for water increases constantly, and must be met. Furthermore, supplies which were originally pure become contaminated. Thus, the necessity arises of purifying an inferior water so as to make it healthful and yet have an abundance for domestic and industrial purposes. The masses cannot or will not afford the outlay and trouble involved in using bottled waters when the public supply is bad. Neither is it found practicable to have a separate system of hydrants and pipes for a scanty pure supply when the main supply is unfit to drink.

If a water be regularly turbid and contains visible dirt, a general outcry for some process of treatment is much more likely to arise than when it is clear and palatable, yet containing the germs of infectious diseases. It is in the latter case that sanitarians find fault with the water. When turbid and colored with dirt and vegetable matter, there will occur numerous complaints from the users. If inspection of the watershed and the evidence of skilful bacteriologic examinations make it seem likely that dangerous contamination exists and cannot be checked or prevented in the future, then it is well to have recourse to filtration on a large scale. This renders the water more agreeable to the eye and the palate, while the process

properly carried out removes nearly all the bacteria.

It is not easy to determine just how much dangerous contamination may be tolerated in a water without manifesting itself in the form of disease and death among those using the unpurified raw water. When a supply is condemned because obviously contaminated, the argument may be brought forward that the germs of cholera, typhoid, and other diseases tend to die out soon after entering a stream or body of water, and that that water purifies itself. It is true that something of the sort takes place. The writer studied this question [1] and found that dilution and sedimentation, the influence of light and oxygen (of the air), and also the antagonistic action of volatile acids in some river, and of the hardy water-bacteria present in all waters, especially in impure ones, contribute to the purification after contamination by the entrance of harmful bacteria with sewage or other filth. Yet if Elsner's test is employed, it is found that typhoid germs survive much longer and are much more prevalent than was formerly thought.[2] Accordingly, and in view of the seemingly small amount of infection causing some very serious epidemics, it is wisest in case of doubt to regard all filth contamination of water as dangerous. It is not safe to assert that all rivers of this country can "purify themselves" within twelve miles, as is often stated. Each case must be considered by itself, and judged independently. Yet it is difficult to convince municipal authorities of this necessity for pure water,

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[1] *Trans. Amer. Soc. of Civ. Eng.*, February, 1891, and *American Journal of the Medical Sciences*, December, 1890.

[2] *New York Medical Journal*, April 10, 1897.

and some of our cities have water supplies which may be classed as dilute sewage. As a consequence, thousands of cases of typhoid fever result among those drinking such impure water, and the disease is much more common among us than in the well-managed cities of Europe.

Recognizing to a certain extent the possible danger in drinking impure water, but also being influenced chiefly by its unpalatability or unpleasant appearance, intelligent people try to do something individually to purify the small amount used by their households. Straining the water through clean flannel or other dense substance, they find it clearer. If boiled, in addition, it is also free from any element of danger to those who drink it. And yet, prepared in this way, it has an unpleasant taste for one not used to it. This is because the two per cent., or less, of air in the natural water has been driven off by the boiling. If we restore this by forcing air through it by a bellows or by pouring the water several times from one pitcher to another, the taste is improved. The addition of a little cold tea, lemon juice, seltzer water, or other chosen savor, disguises the taste. But boiling, though the most generally available and reliable means of artificially purifying water, requires effort, especially when bottles or similar containers are used for holding the sterilized water, since they have to be kept clean. If the water be cooked in the bottles, this involves some breakage. When, therefore, a housekeeper is offered "pure drinking-water guaranteed," for an outlay of 17 cents, which purchases a "self-cleaning water-filter" which has embossed in large letters upon its nickeled metal

case the pretentious words, "germ-proof filter," the temptation is strong to employ such a means of improving the domestic supply. These quoted words are from the printed advertisement of one of the large department-stores of this city. The filter, unfortunately, does not purify the water as claimed, although it strains out coarse dirt and makes dirty water somewhat clearer. It is as valuable as any of the ordinary filters, and is perhaps least likely of all of these to become a source of infection by serving as a breeding-ground for bacteria. It is filled with crushed quartz held in place by two wire screens. Screwed upon a faucet, when clean, it allows a considerable flow of water. Soon, however, the flow is obstructed by the accumulated dirt. If then, such a filter be reversed and the other end be screwed upon the faucet, the coarser dirt is washed out and also much of the finer. Yet considerable fine dirt and, among other things, many bacteria remain attached to the sand. Boiling kills these, but if this be omitted, and the filter allowed to remain unused for some hours, as over night, at ordinary room temperatures, the adherent bacteria will have increased by multiplication in the organic matter present. Accordingly, the first flow of water from the faucet after such disuse of the filter will contain many more bacteria if it flow through the filter than if the filter were not used. The number lessens gradually as the water continues running.

This serves as a type of all ordinary domestic filters, in which class is included for brevity all, whether straining water from a faucet or from a jar, or other receptacle under gentle pressure, and in which

the straining substance is not very dense. In THE MEDICAL NEWS for April 27, 1889, the writer reported the results of prolonged experiments upon very many filters made of the various substances used for the purpose, and since that time he has tested every kind on the market. Nearly every permeable substance has been called into requisition by inventors in this line, such as cotton felt, wood felt, wood pulp, wood, cloth, sponge paper, chaff, wire gauze, charcoal, carbon, polarite, spongy iron, porous porcelain, porous stone, and mineral substances of varying composition in a natural or prepared state, asbestos, and simple sand. As a rule, these are the products of wholly untrained minds quite unfamiliar with the principles underlying successful filtration. Now and then there comes a new variation upon, or an independent application, of some previous idea. The study above indicated, showed that except in so far as it is intended to be a mere strainer of more or less of the visible dirt, the essential virtue of a filtering substance is fineness of structure such as will hold back all bacteria under ordinary conditions of usage for a day or more. If not of such dense material, it is merely of service as a strainer through which bacteria can pass, however well the water is cleared up, and in which they can increase to such an extent that the water flowing from them has more bacteria than that which they are supposed to purify.

This element of bacterial contamination from the filter itself varies with the kind used, and of course disappears for a brief time after the filter is sterilized, as by boiling. Accordingly, such imperfect filters

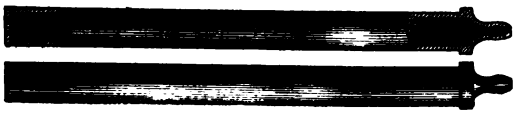
should be simple in construction, commodious, easy to cleanse, and not destructible by frequent boiling. As to their capacity for holding back bacteria, that varies with the density of the filtering substance and its strength and durability. If it tears readily and allows holes or fissures to form, bacteria can of course pass through such breaches of continuity. The simplest and most permeable kind—the sand filter or, rather, strainer above described—holds back so few bacteria as to be practically worthless in this respect. A dense, freshly sterilized flannel bag upon a faucet or a folded filter paper (or even a plug of absorbent cotton) in a funnel does rather better work. Carbon blocks and wood pulp hold back a considerably larger percentage, but allow disease bacteria to pass through and also to increase in the porous filtering mass. Porous stone is still more efficient and when of the finest quality will hold back larger and medium-sized bacteria, such as the germs of cholera and typhoid fever, for many hours. It renders some turbid, silty waters very clear. While the best of these, frequently sterilized by chemicals or by boiling, can be employed by an expert with safety, they are not to be recommended for ordinary use in time of epidemics or when the water filtered is regularly infected, unless it has always been cleaned and boiled a few hours after it has first been used after a previous boiling. This is a requirement which the masses will not observe. So long as a filter renders water clearer, they allow it to strain their drinking-water, regardless of the possibility of bacteria passing through. Asbestos, in carefully arranged sheets, is employed for filters, some of which display great

mechanical excellence. This can be made to yield better results than any ordinary filter, although inferior to the best; but the weakness of the tissue, the bulkiness or complexity of the efficient filters of this substance, and the difficulty of cleansing them, militate against their adoption, although some may be sterilized by baking. Porous porcelain of coarse texture, such as is used in electric-battery cups, is much like porous stone, holding back bacteria for a brief time, but is quite inferior to finely porous porcelain as used in the most efficient filters.

These second-rate substances are bacterially efficient, in proportion to the minuteness of their largest pores and in inverse ratio to the pressure with which the water is supplied. The densest offer the greatest resistance to bacteria and also to water. A corollary of this is the fact that a thoroughly efficient filter cannot be very rapid, and when a given filter yields water much more rapidly than another having the same surface exposed to the crude water, the former is less capable of separating bacteria. Both being under the same conditions, the less rapid yields water freer of germs than the other. And yet the slowest filters are not necessarily in all cases the most efficient, as when, for instance, the slowness is due to a thick mass of fibers or granules which cannot altogether prevent bacteria from getting through, and which, in consequence, must allow them to increase prodigiously in the dirty mass. In no case is slowness a merit, but, because of exhausting the patience of those who use a filter, is to be lessened as much as is consistent with practical retention of "germ-proof" quality.

The only filtering substances which can safely be recommended for household or other use on a small scale, is (1) fine, dense, porous porcelain of standard make and uniform quality tested by the maker; and (2) the prepared infusorial earth cylinders which carry the trade name of Berkefeld. The latter remain germ-proof for a shorter time than the best of the former class—of which the "Pasteur" filter cylinders may be taken as a type (Fig. 1), yet they

FIG. 1.



Pasteur-Chamberland filter tubes. Portion of wall of upper one removed.

are within the limit of safety if cleaned and sterilized (by boiling) daily. They have the great merit of comparatively rapid flow, and are less likely to become broken than the French tubes. Both of the two specified are expensive, being patented articles of foreign manufacture. There are several patterns of filters using excellent porcelain material but made in this country at Trenton and elsewhere. Specimens tested by the writer were quite as good in germ-proof quality and flow as the material of the Pasteur filters. This he has proved by the most rigorous tests carried on in one instance for eight weeks of unintermitting flow, during which time no bacteria came through.

The "Pasteur" filter is also, and more properly, designated by the name of Chamberland, who first

exploited this valuable material, taking out a Belgian patent (No. 69,095) for the exclusive right of using rebaked porous porcelain for filtration. A German patent, antedating this, and a French one dated eighteen months later, might be interpreted as indicating that Chamberland attached importance to the principle of filling with charcoal the space within the metallic casing outside of the porous cylinder. This idea was not utilized by the producers, although in a less popular competitor (Mallié filter, patented in February, 1895) are used flat plates of similar porous porcelain outside of which are corresponding plates of carbon to intercept dirt and prevent speedy clogging of the porcelain by turbid water. Before knowing of Mr. Chamberland's idea, the writer had suggested the same expedient for use with muddy water.

For the Chamberland-Pasteur tubes, semivitrified porcelain is ground up and used in the preparation of the finest product, to give greater porosity. Finely ground silica answers the same purpose, yet if any but the smallest sand-grains are used, it is considered by the makers that the resistance to bacteria is likely to prove insufficient. Some of the best porous porcelain produced in this country seems to be composed of from fifty-five to seventy per cent. of finely ground silex, with between forty-five and seventy per cent. of kaolin clay. This porcelain is quite inexpensive, fairly durable, and as germ-proof as the best French product. The German patent, No. 19,589 (January, 1882), covers the preparation of a similar porous filtering material, as is also the case with the English patents of Bagshaw (1834), Roberts (1859), and Joseph (1870). Yet it is doubtful whether the products were

fine enough to be germ-proof. It was not until 1871 that it was definitely recognized that porous porcelain of the proper sort could remove all bacteria from liquids. This was discovered and utilized by Tiegel, a Swiss pupil of Klebs. About the same time Zahn employed clay cells for the same purpose. In the same way Hiller (1874 or earlier), Panum, and others, as well as Sanderson (1878), utilized porous porcelain. In France, Arloing, Toussaint, and others achieved the same result as Tiegel by using plaster with or without the admixture of asbestos for strengthening the texture. Pasteur, in 1877, used this also, abandoning it later for rebaked porcelain. The admirably adapted cylinder shape still used in the Pasteur filter is due to Chamberland, although somewhat similar patterns had been illustrated in publications previous to his time. The efficacy of rebaked porcelain was announced by him in 1884, through Bouley.[1] While formerly made of two degrees of porosity, the output sold here is now of only one uniform density.

This substance, thus gradually evolved, has never been improved upon as regards permanency of germ-proof quality. A perfect cylinder will remain impermeable to bacteria for days and even weeks, allowing water to flow through in a slow stream or in drops, until the silt and other things carried by the crude water choke up the interstices on the surface. This extreme slowness, increasing with use, is a serious drawback, which, like the brittleness, renders it less popular than its admirable filtering property would otherwise make it. A cracked or flawy cylin-

[1] *Comptes Rendus. Acad. des Sciences*, August 4, p. 247.

der should be discarded, like a broken one. The frequency of mishaps with ordinary careless handling and cooking for the purpose of sterilizing make the Pasteur filter too expensive for the masses, since a new cylinder is retailed for three or more times as much here as in France. There the writer has bought them for about thirty cents. A cylinder which has deteriorated by weeks or months of use, but which is not cracked, can be renovated; yet the ordinary cook cannot be trusted to do this. Careful baking of cleaned and dried cylinders at the high temperature of nearly 300° C. (572° F.) will make the porcelain nearly as efficient as when new. This heat, of course, completely sterilizes the cylinders at the same time. They should be allowed to cool gradually. Another method is to use chemicals. The tubes are well cleaned and then inverted to drain out for fifteen minutes or more. Then, outlet upward, they are filled with, and soaked for at least fifteen minutes in, a twenty-per-cent. lukewarm solution of pure chlorid of lime (or Labarraque's solution or *eau de Javelle* with twice its volume of water). Thereby the albuminoid and mineral deposits in the pores are disorganized. Next they are emptied and then filled with, and lie for another quarter of an hour in, hydrochloric acid diluted with four or five times its volume of water. After this they are emptied and rinsed with boiled water. Another means of sterilizing and regenerating them is to employ similarly, and for twice as long a time, a 1–150 solution of permanganate of potash, followed by a five-per-cent. solution of bisulphite of soda. Very dilute hydrochloric acid tends to prevent the deposition of

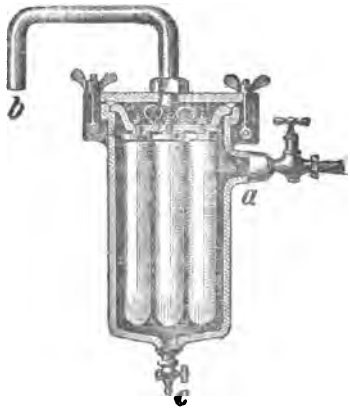
manganic bioxid in the pores. To detect flaws or other imperfections, the manufacturers of good porcelain filters moisten the substance and then apply air-pressure of at least seven pounds. Those which allow air to pass are rejected. The test is very easy for any one to make by means of a small air-pump.

After a few days, or at any rate a week of use, such a filter-cylinder needs to be removed, brushed off, and rinsed. Then it should be boiled gently for half an hour and allowed to cool gradually before replacing in its casing. This is because not even the best filter-substance is germ-proof for an indefinite length of time. Until nearly a decade ago they were regarded as absolutely germ-proof, and even later than that some observers, presumably after inadequate tests, have said that these porous porcelain surfaces allowed no bacteria to get through. In 1888, by a series of thorough tests and checks thereon, made at the Carnegie Laboratory in New York, the author found that, even when the filters were kept cool and when only cold water was used, bacteria passed through soon after the end of the second week of constant usage; so that in time many more were in the filtered than in the unfiltered water. Pasteur cylinders used for the purpose were of the pattern sold at present, and of the best quality, having been purchased by the writer in Paris, of the principal agency, and represented by the seller as perfect. The results of those experiments were accepted, and have since been confirmed by other investigators. Disease-bacteria can grow through this substance in laboratory experiments where everything is arranged to favor the growth; but it has not

yet been shown that this can occur under ordinary household conditions of usage of tightly fixed, perfect cylinders washed and sterilized by boiling at least once every week.

These filters possess, then, a high degree of efficiency as regards the removal of bacteria, and whatever has been said above regarding the efficacy of

FIG. 2.




Battery of filters of the Berkefeld pattern. *a*, inflow; *b*, outflow.

one well-known pattern applies equally to all filters properly constructed of the best porous porcelain. As already stated, American porcelain stands the severest bacteriologic test as well as does the imported material. There seems no inherent reason why all of these should not be fairly good if only made with proper care. It must be borne in mind, however, that when of small surface they cannot be rapid and at the same time germ-proof for any considerable length of time.

When "batteries" are arranged by connecting a few or many of the separate porcelain tubes, of the Pasteur type, or of similar styles, to an outflow pipe by very tight joints, correspondingly increased quantities of pure drinking-water can be obtained from them. These multiple arrangements do not prove quite so "germ-proof" as the simple tubes securely fixed each in its separate metal casing, yet in an institution where a physician, or other person, trained in simple bacterial methods, constantly supervises the arrangement, the cleansing and necessary renewals, and also regularly tests the yield, very bad water can be rendered wholesome by such means. This is proved from the reports of the French Minister of War, based on the prolonged and systematic use of these filters in French garrisons, resulting in a reduction of the typhoid death-rate from one to ten per cent. of what it formerly was, and the cases occurring are said to be nearly always explainable by the use of the ordinary or some outside supply in an unfiltered state. As a point in favor of these and against inferior filters, it is stated that in the British army in India, where charcoal and sand-filters have been used, the number of deaths from typhoid fever has steadily increased since 1884. Such filters are worse than none. Outside of garrisons, military use of porcelain filters proves, with or without the André cleaner and infusorial earth powder, to be unsatifactory, notably in campaigns where the foulness and pestilential quality of the only waters obtainable make an adequate purifier absolutely necessary. However brilliant the laboratory and exposition results, the military filters failed under the

conditions of practical usage. Barthélémy, and also Molinier,[1] very forcibly pictured the inadequacy of these. The best pattern among military filters is called "*filter de campagne*," has fifteen filtering cylinders, and weighs 110 pounds or more.

For use in households where no hydrant water or other piped supply exists, yet where filtration of the drinking water seems necessary, the writer would suggest that some manufacturer introduce circular plates of this germ-proof porous porcelain, perhaps slightly convex on the lower surface, in order that the water might drop only from the center of the plate. This could be held to the necessary cylinder or section of pipe above, and to which it will form a bottom, by screw-clamps pressing it tightly against an intervening rubber ring on the periphery. Although such a plate would filter very slowly, it could be very easily cleaned and boiled. Porous stone of similar pattern is used, but is unsatisfactory, not being germ-proof, although it clears turbid water. Being cemented into the lower rim of the jar above, it cannot well be sterilized. There are various patterns of non-pressure filter metal jars using several porcelain tubes inserted in holes in the bottom. Siphoning arrangements may also be employed. The yield is often contaminated.

The porcelain tube-filters, as also those of the material about to be mentioned, may be used with a union-joint or two-way water-cock. The cumbrously long Pasteur filter is thus rendered more convenient for ordinary sinks, yet the writer prefers the older patterns in which the water flows directly downward

[1] *Archives de Médécine, Navale et Coloniale*, 1893 and 1894.

out of the porcelain cylinder into jars or other receptacles, even though that necessitates a special faucet reserved for the use of this filter. In the case of a specially introduced piping the water should come through iron instead of lead, or a block-tin pipe could be used at twice the price of lead pipe.

A successful rival to the above filter is presented by the (Nordtmeyer) Berkefeld pattern which is

FIG. 3.

Berkefeld filter.

similar in shape and mechanism, but which is many times faster, yielding when clean and freshly boiled nearly a quart of germ-free water in a minute from the smallest domestic model. The porous filtering cylinder is only three inches in length. Closed, like the porcelain cylinders, at one end, the open end is firmly cemented into a flattened, metal funnel having a small central outflow tube, by the outside of which it is screwed tightly inside its metal casing. (See Fig. 3.) No breakable part is exposed when the fil-

ter is attached to a faucet. The household pattern, illustrated here, is so compact that it can be attached to a kitchen faucet and yet allow a jar or pitcher to be placed beneath to catch the filtered water. Its comparatively rapid yield is due to its extreme porosity. The short porous cylinders or cups have walls more than half an inch thick, and are composed chiefly of infusorial earth appearing under the microscope as compressed diatoms (fossil bone-meal) held together by a secret process. They cost $1.50 each, and are more durable than porcelain. The general rule above given, that with increased yield the germ-proof quality is lessened, holds good with these as with other filters, yet they hold back bacteria long enough to render them safe if sterilized by boiling every day or two. The writer, who has tested a number of these during the past two years, has not found one that could not hold back all bacteria for one day. In some experiments, under various conditions of practical usage and with a pressure as high as thirty-eight pounds, when the filters were kept cool (10°-12° C.) during an intermittent yield of more than five gallons daily, they produced sterile water until the eighth day.

From the results of many tests, it may be stated briefly that the Berkefeld filter will hold back all bacteria from one to three days. We can safely recommend them, therefore, even for use with infected waters, on the condition that the porous filtering cup be taken out daily, and cleaned and then sterilized by boiling for half an hour. The water should not be very warm when they are put into the clean vessel in which they are to be boiled and should be

allowed to cool enough to be endurable by the hand when they are taken out. When greatly thinned by repeated brushing or whenever a flaw develops in a porous cup, it should be discarded. It is advisable to have an extra tube on hand, although a single tube can be used for many months. The filtering substance lasts longest if not brushed roughly, but rather cleansed by means of pieces of cloth under a flow of water upon the cup. They do not break by gentle boiling, with little or no ebullition, even if for convenience they be thus sterilized in the same clean vessel in which other things—such as nursing-bottles—are cooked; yet rough handling breaks them. As with porcelain tubes of different makes, when the water is not supplied under pressure, these can be arranged to work with various forms of portable or fixed pumps, singly or in batteries. A single tube thus arranged weighs, with pump and portable stand, eleven pounds, and yields a gallon in two minutes. At least one extra tube should be at hand and also a vessel for the daily boiling, which must not be omitted. For bottling establishments and other users of large amounts of clear waters, batteries of these tubes are successfully used. One of fifteen tubes freshly cleaned and boiled yields seven gallons of sterile water per minute under a hydrant pressure of forty pounds. Testing such a filter under a lower pressure (East 42d St., New York), the writer found the water quite free from bacteria, the very few that were present probably coming from the unsterilized hose pipe used for conducting the outflow. The water was as pure as that from any mechanical filter which the writer has examined. Yet stress must al-

ways be laid upon the importance of frequent boiling of such tubes. Reliance must not be put upon the employment of automatic means of cleansing them by the use of powdered infusorial earth to the neglect of boiling several times a week, although bottlers are apt to disregard such injunctions. In a carefully managed hospital or institution under proper scientific medical control these battery filters can produce water entirely free from germs.

All things considered, the simple form of the short-cylindered Berkefeld filter is to be recommended as the best for household use when there is a hydrant supply needing filtration, but it must be repeatedly emphasized that frequent boiling of the porous cup is essential to perfect results. While thus commending this filter, the writer would not disparage the best porcelain filters. In his own residence, both kinds are in regular use and both yield sterile, wholesome water.

As compared with the use of these germ-proof filters by the few intelligent people who will regularly give them the requisite amount of care (in itself very trivial, but yet indispensable) any other filtration of drinking-water is inferior. Even the best gravity-filters are not perfect and yet they are in every respect better for a city than the individual use of any ordinary domestic filter; for most every pattern in the market is worse than none and vastly inferior to the employment of boiling for purifying water at the time of an epidemic.

Skilfully constructed sand-beds, usually an acre more or less in area, are capable of purifying river and other surface waters very acceptably, provided

there has been formed upon the surface of the fine, top sand layer a delicate and continuous film of confervoid vegetation, silt, and other fine particles which occur in such natural waters as require filtration. Since the first half of this century practical English working has demonstrated this very completely. This principle was introduced into Germany during 1856, but the true merit of the process and the essentials upon which its great hygienic value depends were not fully appreciated till more than a qurter of a century later. It was carried out in a very successful form at the Tegel river-lake supply of the Berlin waterworks in November, 1883, to remove the troublesome, pipe-obstructing growths of *crenothrix* which resulted from the admission of deep well-waters. There the process has been studied most carefully since that time, and the thorough chemic and biologic results, noted by Proskauer and others, have furnished an invaluable guide to the understanding of the conditions which underlie success with such filters. So, too, have the corresponding investigations by the English Local Government Board and by the Massachusetts Board of Health, whose results are given in detail in their reports published during the last seven years.

It is found that, unlike sewage filters, the sand-beds employed to purify water for public supply do their important work chiefly by virtue of the upper layer of fine sand, and particularly by reason of the presence of an unbroken, fine film allowed to settle upon the surface of the sand before the filtering begins. In proportion to the perfect quality of this very fine straining medium is the efficiency of the

filter as regards the separating of all (or practically all) bacteria from the water that passes slowly through the filter-bed. This removal of bacteria is the criterion of hygienic merit. As the flow through is at the slow rate of not much more than four inches an hour, considerable chemic purification of the water takes place during its downward passage through the masses of sand and gravel. On the immense area of sand and gravel surfaces bacterial slime (zoöglea), containing great multitudes of nitrifying bacteria, is attached. As the water, containing one per cent. of oxygen or more (if quite cold), flows slowly over these, the putrescible organic matters present are, to a varying extent, still further converted into inorganic compounds. This chemic change is due to the vital activity of the permanently adherent nitrifying bacteria whose presence, especially at the top, makes an old filter more efficient in this respect than a new one; yet, as Gill and Piefke first showed, simple washing does not cause sand to lose this zoöglea slime. Before the paramount importance of the separation of bacteria was recognized, greater stress than now was laid upon determining the degree of this chemic action. At the most, the chemic improvement is, as Frankland expresses it, "slight," and is not of much hygienic importance as compared with the bacterial efficiency of the film on the surface.

Suppose, then, a plant carefully constructed. It has a settling-basin large enough to hold several days' supply of crude water. Each filtering-basin is an acre or more in area; the firm walls and especially the bottom are water-tight by means of several

inches of good concrete. There should be no ventilating pipes rising through the bed, and no projection or irregularity on the walls to restrict the facility of maintaining a continuous, smooth surface of sand. That of the upper portion of the bed is very fine, although it is not found best to have the grains less than one-fourth millimeter ($\frac{1}{100}$ of an inch) in diameter. Two feet or much more of fine, washed sand (although some have even less than a foot and yet work very satisfactorily, as at Alexandria, Egypt[1]), are supported by coarse sand, and this by gravel and broken stone. This makes the filter about six feet deep. In some the sand rests on two courses of porous brick, and is reported to work well. The writer has not tested such thin filters. After filtering for from one to eight weeks, according to the condition of the crude water supplied, the sand surface will have collected so much slime and dirt that it is clogged, and water passes through only very slowly under any safe pressure. Then the inflow is stopped and water is drawn off through the outflow sufficiently to render the sand firm. Practised employees, having broad boards attached to the soles of their boots, go over the surface systematically, shoveling off the upper half inch or more of the fine soiled surface-sand together with the accumulated sediment above it. This is then removed to a neighboring washing arrangement. If this scraping has caused any disturbance of the even surface of the sand, this must be completely rectified, then all made smooth and perfectly level. At times more sand has to be added very carefully to replace that

[1] *Ann. d. Hyg. Publ.*, 1895, p. 487.

taken away by repeated scrapings. It is largely to obviate this that the sand-layer is made several feet thick at first, for the bacteria-separating efficiency may be equally good or nearly so if even less than a foot of fine sand be present, yet the brief increase in the number of bacteria, with the effluent which comes just after cleansing of the surface, is greater in shallow than in deep filters, probably because of mechanical disturbance of the bed in its deeper parts. The majority of experts think five-foot layers of sand yield better results than very thin beds.

After being cleaned and leveled, the filter-beds should have some of the purified water returned through the outflow pipe until the surface of the sand is just covered. Then crude water is gently introduced, through the regular supply-pipe, until the ordinary working height of three or four feet is reached. Care taken to accomplish this refilling without any disturbance of the sand surface is repaid by superior efficiency of the filter from the commencement of working, and by these means little or none of the first effluent may have to be wasted on account of containing too many bacteria. Before any water flows through, that carefully introduced should be allowed to stand for twenty-four hours. At the end of that time the all-important film will usually have formed upon the sand surface. If the sediment be insufficient, some coagulant, such as alum or iron salts, may be added to produce this; yet the natural film, especially if of minute earthy particles, works best. When once the film is sufficient to separate bacteria properly, as determined by the usual gelatin-culture test of samples allowed to flow through, but not yet

turned into the hydrant supply, the filter may begin to work. The impure water above the filter-bed is constantly maintained at the same level, not exceeding fifty inches, and the outflow is automatically regulated so that not much more than four inches flow through the sand each hour. That gives a yield of not more than from two to three million gallons per acre in twenty-four hours. This is the highest safe yield generally considered practicable. Yet in the Twenty-seventh Report of the Massachusetts State Board of Health (1895), pages 517 and 518, it is stated that upon experimental filters of very small size ($\frac{1}{20000}$ of an acre) filtration at the rate of from five to nine million gallons daily has been shown capable of removing more than ninety-nine per cent. of all bacteria! The unfiltered water contained several thousand bacteria, being from the Merrimac River, which at Lawrence contained considerably less than 30,000 bacteria per cubic centimeter, the average being over 16,000. The sand was five feet deep and 0.38 millimeter ($\frac{15}{1000}$ of an inch) was its "effective size," this term indicating the "maximum diameter in millimeters of the finer ten per cent. of the sand grains." (See Twenty-fourth and Twenty-sixth Reports, pp. 541 and 703, respectively.)

Intermittency in operation, while necessary for sewage filtration, is both practically and theoretically less satisfactory than constant operation without cessation from one cleaning-time to another. This is especially so during winter. These filter-beds work continuously, then, when once the water is started running through them. The clearer the crude water, the longer the interval between cleanings.

It is an advantage to employ settling-basins as large as practicable as a preliminary to the filtering process. They are indispensable when the supply is very turbid, such as are, notably, the waters of the Ohio and Missouri rivers. Gravity sand filter-beds, properly conducted and carefully managed, afford, on the whole, the most reliable artificial means of rendering an impure water fit for both domestic and general consumption. At their best they not only clarify the water, but also reduce the average number of bacteria to considerably less than one per cent. of the amount in the original crude water. At the same time, practically all disease bacteria are removed, yet some filters yield very poor results, whether because of incompetent management or through inherent defects in the construction, or by forcing a sand-bed to produce beyond its capacity. When the surface is frozen the results are more apt to be defective.

The cost of constructing a complete filter-bed an acre in size varies from $20,000 to $100,000, according to the topography, the availability of suitable sand and other material, the cost of labor, and other elements. An open filter-bed, having tight concrete bottom and sides, with proper regulators and piping, not including settling or receiving basins, may roughly be said to cost at least $1 for every square foot of filtering surface. Half as much again must be added for a suitable covering to prevent the growth of algæ and keep the water of more even temperature. In northern localities some covering is desirable because of the considerable impairment in efficiency caused by ice during winter.

At Hamburg, open filters are employed and successful cleaning of an ice-covered filter is accomplished, without the usual removal of the water, by using a sort of trawl scraper suspended at the right level by floats and moved across the sand-bed. This is explained and very well illustrated in the *Journal für Gasbeleuchtung and Wasserversorgung*, 1897, page 4, a portion of the illustrations and summary of which appeared in the *Engineering Record* for May 1, 1897.

When suitable fine sand is not procurable in the neighborhood, the expense of procuring it may be too great to warrant its use. Crushed quartz, especially adapted for sand-filters, costs at the rate of more than 60 cents per cubic foot, weighing about ninety pounds. When the cost of the sand is thus prohibitive, and when ground enough properly located is not to be obtained at a reasonable price, recourse may be had to mechanical filters, which occupy much less space and require much less sand, since water flows through them fifty or more times as rapidly as through the same area of gravity sand-bed. While these are more expensive to construct, the operating expense is much less than that of mechanical filters, being mainly that of cleaning and restoring the surface. It may be roughly estimated at nearly $10 per million gallons of filtered water. It is claimed that a few plants require much less than half this outlay, while others cost half as much again. At Lawrence, Mass., the cost was less than $7 per million gallons during 1895. Nearly forty per cent. of the expense was for removing ice, while less than half was for scraping and replacing

sand. Nearly fourteen per cent. of the charge was for washing the removed sand.

Filter-galleries, situated in the low banks of rivers, are fed rather by ground waters from the upland side than by filtration of river water, which does not filter with practicable speed through the very resistant mud and silt. When the river rises and its water flows into the galleries through coarse sand and gravel, it is likely to render the supply less wholesome by reason of the ease with which bacteria can pass through. Thus, at Dresden, where a ground water-supply of this sort is used for a demand a third larger than originally planned for, it is found that when the Elbe rises more than a meter above its normal level, the bacteria of the water (usually twenty to forty per cubic centimeter) increase to several thousand. With this increase a greater number of gastro-intestinal disorders than usual occur, especially among infants, and their mortality is increased (Meinert). For such filter-galleries it is essential to have water-tight barriers constructed to keep out any inundation or any inflow of water through ground that is not of a perfectly filtering character.

While figures may prove very misleading when not carefully interpreted in the light of the exact conditions obtaining, it is not uninstructive to give a few statistics to illustrate the hygienic value of good filtration. The great cholera mortality (8200) at Hamburg during 1892, while the similarly situated neighboring city, Altona, using worse water from the same much-polluted river was comparatively free, was because the latter had good filtration, while at

Hamburg the old filters were defective and the new ones not quite finished. The typhoid mortality there is only 58 deaths per 1,000,000, while at Altona it is 41, and at Berlin, between 40 and 65. Amsterdam, filtering water from sand lakes or canals, has but 28 deaths per 1,000,000. These figures compare favorably with those of cities supplied with first-class mountain water, Munich having 32, Vienna 40, and Nuremberg 42 deaths from typhoid per 1,000,000. As against the results of these naturally or artificially pure waters, may be quoted Maline, supplied by shallow surface wells, the mortality there being 993.[1] This, however, is exceeded by the Chicago typhoid death-rate for 1891, which Hill gives as 1600. He gives that of Pittsburg (for 1893) as 1110, St. Louis (1893) as 1030, and of Lawrence, Mass. (1892), 1020.

Artificial sand-plate filters (Fisher system) are said to be employed with great success at Worms, Westerhüsen (near Magdeburg), and at the Müggel-lake intake near Berlin. The writer has never tested these, but credible reports would make them seem about equal to good gravity filters as regards bacteria-removing efficiency, while the yield is proportionately much greater. If thorough tests, carried out impartially at the last-mentioned station, confirm the excellent results claimed elsewhere, it may well be believed that this method, which seems the revival of an older idea, is practicable on a large or small scale. The plates are easily and quickly cleaned and, like mechanical filters, have the advantage over gravity sand filter beds that they can be sterilized

[1] Smee, *Lancet*, March 13, 1897.

promptly and completely by steam in case of typhoid, cholera, or other infection having entered. They are very strong and have the especial merit of simplicity and freedom from increase of bacteria at the beginning of the flow just after cleansing, as also under a considerable increase of pressure. This would mean that attempts to overwork them, so common with mechanical sand-filters, would not produce such bacteriologically bad water as results from the latter under such circumstances. They are said to be composed of fine sand and finely ground soda-water-bottle glass mixed and heated to 1200° C. The slabs are nearly forty inches square and four inches thick. They are screwed together and the edges cemented. A number of them may be arranged in line to form a pipe into which water filters from without.

In some cases in which filtration is deemed necessary for a municipality, an industrial plant or even individual systems, the slow, gravity-sand-bed system above considered appears impracticable, or less desirable than mechanical filtration, even for a large supply. This may be due to remoteness from a supply of good sand, or the ground may be limited, or other economic reasons may obtain. Whatever make be selected, even including the invertible patterns as that of Kröhnke or of Carl Schultz, it will be quite similar to its numerous rivals. These mechanical filters operate by causing the crude water to flow rapidly, usually under hydrant pressure, through comparatively small masses of fine sand, coke-powder, or similar substance enclosed in cylinders of wood or iron. Mere sand (or coke, etc.) alone will

not be capable of holding back many bacteria, nor will it strain turbid water sufficiently clear, but the preliminary addition of one or two (or more) parts of a coagulant, such as an alum or iron salt, to one hundred thousand parts of water usually causes the formation of a gelatinous film which, settling within an hour upon the surface of the sand and also to a certain extent between the grains, when skilfully managed will cause such a filter to produce clear water which compares favorably with that from good gravity sand-filters. A permeable bottom supporting the sand allows water to flow downward into the outlet and also permits purified water to be driven backward for the (from one to five) daily washings. Upon this a layer of coarse sand or crushed quartz about a foot deep should be placed. This supports a two-foot layer of find sea sand or crushed quartz (or coke, etc.) of an effective size of from .3 to .5 mm. (from $\frac{1}{80}$ to $\frac{1}{60}$ of an inch). Into the space above this, crude water for purification is introduced after alum has been added.

Both as an expert trying to aid in obtaining the best possible results, and also as an impartial scientific observer wishing to determine how widely such filters vary in efficiency, the writer has tested many of these. While his investigations have been less complete than those conducted at Providence, R. I., during 1893, and at Louisville, Ky., during 1896, as regards thorough and constant study with one kind of water, they yet serve to show the results accomplished by such filters under ordinary as well as expert management in actual every-day use under practical working conditions. Tested regularly and irregularly

in this way, mechanical filters generally show less constant and perfect results than do gravity sand filter-beds, but this is more owing to lack of careful management and insight into the principles of operation than because of any inherent defect in the method. Almost all of the various makes will do excellent work, clearing muddy water and reducing the number of bacteria to less than one per cent. of the original amount; and yet some of the best makes, as typified by filters established in permanent operation, and referred to in the makers' circulars, have been found to produce an effluent having more than fifty per cent. of the bacteria (of all varieties) occurring in the crude water. On the other hand, some of them at times are found, without any unusual care, to produce water almost entirely free from bacteria, provided they are worked at much less than their full capacity. Others, when overworked, offer insufficient resistance to bacteria and turbidity. They are comparatively complex and usually dependent upon constant skilled supervision. Their all-important bacteria-separating film, unlike that of the surface of gravity sand-beds, not lasting for weeks perhaps when once established, but rather being destroyed by the necessary washing at least once daily, and perhaps five times, the operation cannot be so well controlled as that of the slow filters. With the latter, the yield may be stored in a separate basin until the usual gelatine test shows whether the film is separating bacteria properly. But with mechanical filters the essential filtering-film must have been removed, as also a number of subsequent ones, under conditions of economic working, long before a bacteriologic test

can have been completed. This is a very important consideration especially at times of epidemic and actual infection of the water.

A point in favor of mechanical filters is that they can be completely disinfected by steam or boiling water, the most satisfactory of all means. Within these filters the sand does not remain in as permanently good working condition as in those parts of gravity sand-beds which lie beneath the surface. Accordingly, it needs to be steamed or else scoured with a four- or five-per-cent. solution of caustic soda, or both processes may be employed, at least twice yearly. Otherwise, bacteria, not removed by the daily washings, grow in time so numerous as to contaminate the effluent, and among these may be disease germs. If their presence be suspected, and certainly if demonstrated by culture-tests of the sand or water, sterilization of the filter is necessary. Mechanical filters involve considerably greater expense for operating than do gravity-beds. On the other hand, the plant costs less than the best water-tight slow sand-beds complete. Although alum costs less than two cents a pound, this proves a costly item when used for large quantities of water. When the filter is working well, the proportion of alum used may be only one part to a hundred thousand parts of water, or less than half a grain to the gallon. In practice, however, this proportion of the coagulant is often considerably exceeded, whether through carelessness or because of very muddy or peaty quality of the water, and this of course increases the expense. From such permissible small amounts of alum as remain unchanged in the purified water we

cannot recognize any danger to health or detrimental influence upon boilers or industrial processes. This alum is almost entirely decomposed in making the desired film of flocculent alum hydrate and of a combination with organic matter present. The sulphuric acid set free combines with the earthy carbonates present and thus tends to become neutralized. At the beginning of filtration, after the film and dirt have been washed out, an excess over the usual minute amount of the coagulant is commonly added to hasten the formation of the necessary film. Whatever of the salt remains uncombined is washed out with the first few minutes' flow of water. Since this water has very many bacteria present, it is purposely wasted from well-managed filters. This amount of water wasted varies from three to eight per cent.

While only vertical cylinders are spoken of above, it should be mentioned that horizontal cylinders are in some cases employed in large plants, yet both are the same in principle. Even an invertible one, such as that of Mr. Carl Schultz, or like those used for the Kröhnke deferrating process, work in practically the same way, the peculiar construction being only a modification designed to facilitate cleansing. Mechanical filters may be combined to any number to make "batteries" and thus millions of gallons be produced by one plant. Individual filters vary in size from one foot to ten feet in diameter. Since the water is meant to flow through nearly sixty times as rapidly as through a slow gravity filter-bed, a filter ten feet in diameter, and having an effective filtering surface of about seventy-eight square feet, would be expected to yield from 100 to 250 gallons

per minute, but should not be allowed to exceed that amount. Filters one foot in diameter are capable of yielding 100 gallons per hour, and in complete working order cost not far from $100. They are intended for private houses and serve the purpose of clearing all the water for the household under ordinary conditions, but they cannot respond to sudden demands for a large quantity of good filtered water as the combined draft for laundry, and other purpose, coming at the same moment would produce unsatisfactory water. Accordingly, storage-tanks are needed, and wood will usually be selected as the material. This, and also the filter, usually do not receive careful attention and the water is then too often likely to yield many bacteria when tested. Pure drinking-water would be better insured by a battery of Berkefeld filter-tubes kept in good order and sterile, which, even at present high prices, would prove less costly. A drawback to some of the best varieties of mechanical filters is threatened litigation if the coagulant be added just as the water enters the filter. The Hyatt patent, controlling this, expires within four years. The use of a preliminary settling-tank or basin is not thus restricted, but seems less satisfactory.

Sedimentation is of recognized value in reducing the number of bacteria as well as tubidity of a mass of water, which can remain at rest or nearly so as in storage-basins, and in lakes, or lake-like enlargements of rivers, when the current is very sluggish. Various bacteriologists have found this to be the case, and the writer's studies of lakes and reservoirs, especially when much silt was present, have tended to

confirm this view. The presence of settling-basins, with or without ærifying arrangements for the inflow, is of value as an auxiliary, but is not of enough absolute potency to warrant exclusive reliance upon such means. In most of our streams and bodies of water which receive bacterial contamination from sewage and other filth, sedimentation does not seem to accomplish much. It is, as already said, the element of great dilution which seems to be the chief factor in improvement of the water. Light (which favors the production of algæ) lessens bacteria, especially when the water is well aerified, according to most experiments conducted in that directions; and strife among bacteria is regarded as aiding the process. If a small volume of infectious washings from a privy-vault, manured field, or sewage outlet, mingle with abundant water of a large stream, the tendency to diffusion throughout the large volume of water causes a sample taken lower down stream to show many less bacteria, as well as greatly diminished chemic impurity, unless some intervening contamination complicates the conditions. In small streams, flowing through densely peopled industrial districts, this natural purification is so much less potent that English investigators have declared that a stream much polluted cannot again become pure. In our copious rivers, as also on the Continent of Europe, such an assertion is easily disproved, yet the experiences of some of our cities show that extreme vigilance must be exercised if the water-supply comes from a contaminated river. An arbitrary statement that fifteen or even fifty miles of flow insures the destruction of all harmful contamination is not always sub-

stantiated by facts. In this connection, although the same principle has not been shown to be operative in our streams, it seems proper to mention Hankin's observations on the peculiar quality of the water of the great rivers of India[1], in which certain acid substances, volatile on heating, destroy all cholera bacilli that enter the streams, although these dangerous germs increase vigorously in well waters of those regions.

Observation shows that storage for months tends to lessens or remove color and odor from water; but when light is not excluded, algæ are likely to flourish, if nitrogenous elements in an assimilable form, and special mineral constituents, and other conditions, are present to favor their growth. Even when such storage is practicable, it is always preferable to have water in the beginning so pure that none of the causes of odors, such as infusoria, sponges, nostoc, etc., or any dead animal or vegetable matter, are likely to occur. Although such waters are not known to have directly caused disease, a fishy, or other repellant odor or taste, can make a water so offensive that people will not drink it, and it will arouse more emphatic protest than even the known presence of disease-causing germs. If a reservoir be created by damming up and overflowing fertile slopes or meadows, the soil should be dug away so as to remove roots of grass and bushes, may be to a depth of more than two feet; otherwise, decomposing organic matter may cause bad odors to arise in water stored there.

Heat kills the germs of disease and all other living

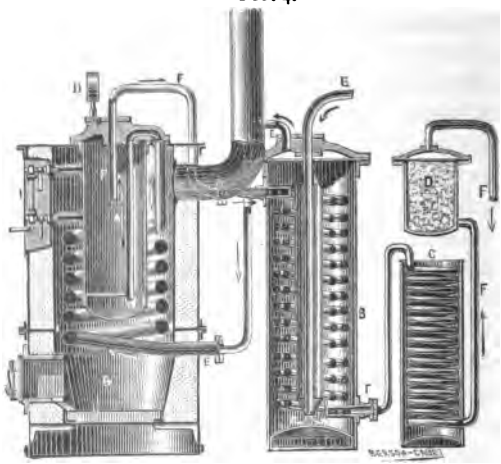
[1] *New York Med. Jour.*, April 10, 1897, p. 503.

things. If water be boiled long enough, no bacteria or other organisms will remain alive in it. This, in its practical bearings, has long been recognized. The writer pursued a prolonged and careful series of experiments some years ago in this country (chiefly in the Carnegie Laboratory) and in Koch's laboratory in Berlin, employing various natural and artificially infected waters, and demonstrated that simply bringing water to nearly the boiling-point, and then allowing it cool gradually, sufficed to destroy the elements of infection. Thermophilic bacteria and some common kinds require very much longer heating for their annihilation, but practically a brief heating answers the hygienic purpose. This means can be employed almost anywhere and is to be recommended at least as a makeshift under urgent circumstances, as when the water-supply is bad or even suspicious and yet no adequate purification obtains. Since boiling drives off air and also carbonic-acid gas (causing the separation of lime and magnesia), the water in most cases is thereby made somewhat less palatable; although the taste of some malodorous and unpalatable waters is improved by heating. Subsequent aerification, as by use of a bellows or more elaborate appliance for exposing the water to as pure air as possible, effects an improvement. The addition of a small amount of tea improves the taste for some people.

Within the last ten years several economic contrivances for heating water to the boiling-point and cooling it to within a few degrees of its original temperature have been perfected by Yaryan, Siemens, Grove, Rouart, and others. The apparatus of the first-named inventor, as designed for the use of a

large municipality, was carefully tested by the writer in Toledo and found capable of completely sterilizing the hydrant water of that city. The principle employed by all these independent inventors is a series of pipes so arranged that by convection the cold inflowing water cools the outflowing sterilized stream and is at the same time gradually heated before it arrives at the boiler. Thus a minimum expenditure of

FIG. 4.




Water Sterilizer.

fuel is required. The accompanying illustration (Fig. 4), supplied through the courtesy of Rouart Frères of Paris, shows an apparatus which is claimed to have achieved a practical success. The arrows indicate the course of the water from the inflow E. to the outflow F. The yield is of better quality than non-aerified, boiled water, since not much more than half of the oxygen is lost in a well-constructed ap-

paratus. Lime and magnesia are considerably reduced, as also are the other mineral salts and the organic matter. Despite the theoretic merits of these economic sterilizers for water which is clear but infected, they have not found practical acceptance unless in a very limited way.

Distilled water is considered desirable for the most economic and satisfactory results in certain processes, as also for human consumption, when the natural supply is of poor quality, and especially when it is charged with poisonous or other mineral salts. To supply this need at a low cost, on a large scale, excellent stills exist. On shipboard, particularly when the vessel is on a prolonged voyage or cruise away from ports where good, fresh water can be obtained, distilled water, easily prepared and palatable, is not only very convenient as saving the space of storage-tanks (too often defective) and casks likely to become foul, but is also of considerable sanitary value. This is evidenced by statistics of the naval and marine service before and after the introduction of the regular use of the Baird, Niemeyer, and other excellent stills. All properly constructed ones yield water free from bacteria if due care be taken to have the condensing and outflow portion and any filter there sterilized by steam before using. Instructions should also be given to waste for ten or twenty minutes the first flow of water after long disuse of the apparatus. This is to avoid chemic impurities. Lead should never enter into any part of the construction of tanks or stills, for the danger of poisoning is considerable, even from solder. Tin shown by assay to be pure should be used for joints of tin plates and tubes, although

more difficult to work with than solder. Iron rusts, and is, therefore, inferior to well-tinned copper plates or drawn brass coils well tinned inside and outside. Abundant sea-water cools the steam coils by flowing in at the bottom and out at the top on one side of the tight casing inside of which are the smooth or corrugated coils of vertical pipes into which steam under low pressure enters at the top. At the lower end of the condenser the distilled water flows out or is drawn out by a pump where a filter (of asbestos or pure bone, charcoal, and sand) is present, for the purpose of relieving the water of the whitish flecks and oily taste which come from slight quantities of lubricating oil going over with the steam. When the steam pressure is high this oily taste is more likely to occur than when the pressure is quite low, as from an evaporator especially introduced for the sole purpose of vaporizing sea or other water in order that it may, on condensation, become distilled water. From a perfect still very pure distilled water can be produced, having none of the salt or other undesirable constituents of the original water. If petroleum lubricants are used, they tend to cause an increase of ammonia above the small amounts which can be detected in almost all distilled water. At the end of every voyage the filter attached to the condenser of a vessel's still should be cleansed and sterilized by steam sent through the still. The distillate should also be tested from time to time to detect any leakage of the cooling salt water into it. One need only add a drop or two of a solution of silver nitrate, slightly acidulated with nitric acid. If any salt has entered the distilled water, this reagent will produce

a visible whitish cloud or precipitate when added to the water in a glass.

Aerification of distilled water should be so managed as to introduce no bacteria, and certainly no harmful ones. Previous filtering of the raw water and boiling long enough to insure the driving off of the more volatile organic matter previous to distillation is regarded by Mr. Hallock, the expert chemist of the Schultz establishment, as the best means of preventing the usual taste of ordinary distilled water, and more satisfactory than the preliminary addition of such an oxidizing agent as permanganate of potash. For the Witteman still the water is twice boiled and superheated before being vaporized. Thus, for artificial ice or artificial mineral waters the maker who is careful enough to use distilled water avoids the necessity of aerifying it, which process too commonly allows the introduction of bacteria of numerous kinds which may be in the air, and which, despite cotton and other filters of the air, are always found in waters of most establishments.

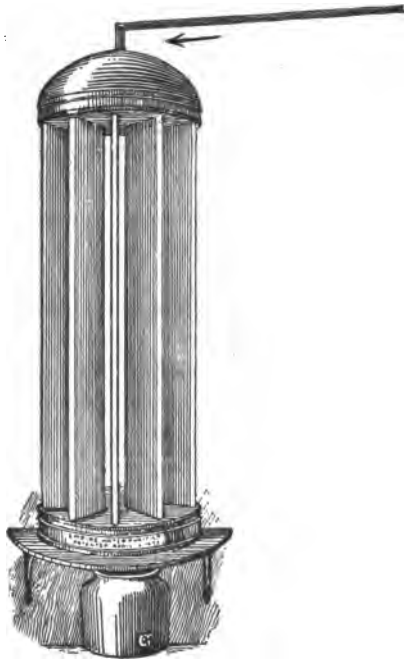
There are localities, notably in desert regions, where the available supply of good drinkable water is so deficient that the providing of distilled water in large or in small amounts is a hygienic necessity. Aden (steamer point), on the Arabian coast, affords an instance where large evaporators of American and other types are employed for supplying water. Especially when the apparatus uses an exhaust pump is it important to test for the presence of lead contamination or its probability. In our western mining regions and in certain grazing districts in the "Great American Desert," water is often so impure and un-

palatable as to require distillation in order to be rendered fit to drink. When the supply is copious enough to permit an abundant flow of cold water for keeping condensing-coils or plates cool, use may be made of the common form of glass or tin spiral tube connecting tightly with a large closed kettle or vessel in which water is kept boiling. The resulting steam goes out of a small opening into a long pipe, which rises at first and then, like the coil into which it conducts the steam for condensation, descends gradually. The spiral tube or coil is fixed in a pail of freely wasted cooling water, and conducts its condensed steam as distilled water outside by passing through an opening on the side of the pail. By bending this distilled-water tube upward and then downward so as to form a siphon after it emerges, contamination by leakage of the cooling waste water is obviated. Such a primitive arrangement produces distilled water that is sterile if only the inside of the condensing-pipe be sterile beforehand. So too do tinned copper drums or pipes through which water is condensed from steam in an automatic way, the air outside these large-surfaced conductors cooling them sufficiently to secure condensation. Attention is needed only to keep boiling water in the kettle. The joints should be quite tight.

During the last ten years the writer has seen various adaptations of this principle of using cool air for condensation, and those which he has tested have proved capable of yielding wholesome water, free from bacteria and mineral matters, except that lead has been evident when even a little solder has been used for the joints. This is especially the case when the

apparatus is new. If such a faulty new condenser must be used, the first few gallons ought to be wasted, and also some after disuse. Tests show that it is safer to tolerate a small leakage of steam

FIG. 5.



Domestic condensor. Arrow indicates direction of inflow of steam. Distilled water flows out at base.

from a well-made condenser than to use solder, instead of tin and the blow-pipe, for stopping it. The accompanying illustration (Fig. 5) shows the appearance of a domestic condenser of the most effective kind.

These are usually made as a series of drums communicating by short pipes with tight joints, as illustrated by Sears in the *New York Medical Record*, March 21, 1896. Practically the same idea is embodied in a subsequent model used for the "400" still, which has a cooling surface of over 1½ square meters. These stills yield from a quart to a gallon per hour, according to their size, and somewhat according to the outside temperature and the way they are worked. The steam kettle may be heated on a stove, but a more constant heat can be obtained from a central-draught "mammoth" lamp or an "oil-gas" stove or a gas stove. When gas is supplied under sufficient pressure, and when water abounds for cooling the steam, a still of the Jewell pattern or the "Domestic" style can produce a gallon or more per hour. The writer has used the latter kind during the last nine years, and found it satisfactory. There are various American and foreign domestic stills employing a comparatively small tinned surface for condensing, and flowing water is used (and also ice) for cooling this. They are generally less satisfactory than the styles above indicated, although they produce distilled water of fair quality.

Chemicals, in which class may be included alcohol in beverages and also the employment of electricity in any form or adaptation, are not to be recommended or relied upon for ordinary practical sterilization of drinking-water. It is true that various reagents of this class if acting in sufficient strength and for a sufficient length of time are capable of destroying bacteria in water. We know that, by admixture of just the proper amount of certain chemicals, foul water and even

sewage can be clarified and even sterilized. The importance of the skilful use of quicklime under certain conditions for the removal of organic matter or for lessening the amount of lime already present, is recognized. Like alum, iron, or similarly acting coagulants, it has a distinct utility when indicated for the purification of bad waters, but the use of these chemicals, or of permanganate of potash or such chemicals as bromin (urged by Schumburg), or any others in sufficient quantity to produce immediate sterilization of bad water in all cases, may make it anything but wholesome or palatable. Boiling is in every way more reliable and therefore preferable.

It is quite possible with time to produce, under laboratory conditions, the death of all the bacteria of a given sample of water, or at any rate cholera bacilli, if even so mild a natural acid as lemon juice is added to it. Stronger agents are of course more potent, but it is unwise to recommend that such uncertain means be relied upon by the masses in time of epidemic. Some abominably tasting and rather harmful drugs are at times thus advised without giving the authority and without retraction. Even in serious technical literature fallacious statements of assumed fact are encountered. Thus, Traube asserted that a minute amount of lime chlorid sterilized water. Although obviously erroneous, the statement attracted some attention because of the high character of the organ of publication. Various tests showed that at least thirty times as much as the amount specified was needed. To sterilize bad water in ten minutes one must use of lime chlorid no less than 15 parts to 100,000 parts of the water. Even more

may be required if the water contains much organic matter, for that takes up the chlorin so rapidly as not to leave enough to act on the bacteria. The lime chlorid is not easy to dissolve and a sufficient quantity may make the water very hard as well as cloudy, thus necessitating filtration. So, too, the alum process urged by Babes was proved to be inadequate. Although in some cases 4 parts of alum to 10,000 parts of water prevent increase of bacteria, the writer determined from repeated experiments that under practical conditions even this considerable amount could not always be relied upon. Peroxid of hydrogen acting, like ozone, because of its contained active oxygen, if in the proportion of 1 part to 1000 of water, sterilizes it in twenty-four hours, but when organic matter is present this agent is not to be relied upon. All such agents act in too complex and uncertain a way to be comparable with boiling.

Electricity deserves mention chiefly because of the prominence which has been given to it. If conducted through water, a dissociation of the molecules into the component hydrogen and oxygen occurs, the latter being set free at the positive pole, and it can exert a destructive influence upon bacteria, especially in sunlight or strong daylight. This affords an interesting laboratory demonstration, but it costs too much for ordinary employment and is otherwise impracticable. Electrolysis of common salt, present in water, causes the salt to break up into sodium and chlorin. These tend to recombine and one of the products is chlorinated soda, just as chlorinated lime results from electrolysis of lime chlorid. By reason

of their available chlorin, these resultant salts are powerful disinfectants and are known to be destructive of bacteria if enough of the fresh, powerful chemical be present, but this is merely a chemic action and no other and subtler force than the chemic products ~~are~~ do operative in the process. Because of obvious uncertainty as to the exact quantity of these evolved chemicals when they are introduced in this indirect way, it is preferable that they be added in a precisely known quantity. This is also the more economical way, although the use of such chemicals cannot be regarded as a desirable means of sterilizing drinking-water.

It should be mentioned that when lime is used in the largest permissible amounts to clarify sewage, the effluent water is almost never free from bacteria, and in no case is wholesome even if used at once. If stored or poured into a river, its alkalinity favors the growth of algæ and other forms of water vegetation. The effluent from a properly managed sewage-farm is much more suited for admixture with water of streams that further on are used for water-supply. Natural filtration by the soil or efficient artificial filtration must be considered—like boiling—as vastly superior to chemic and electric means of sterilizing water. Any insoluble substance in minute particles, which is clean and just heavy enough to sink slowly in bacteria-laden water through which its innumerable grains or flakes are diffused, will in settling carry down a considerable percentage of the bacteria. Even rapidly sinking particles, such as grains of sand, can experimentally be shown to produce this result to a certain extent although less completely

than particles which settle more slowly. The gelatinous sediment resulting from the addition of alum or other coagulant is very effective in this respect. So, too, on adding fresh lime and also soda to reduce the hardness, the fine resultant precipitate in settling causes many bacteria to sink with it. But this removes only a portion of the bacteria, for it is a mechanical removal and not a chemic action, unlike the total destruction caused by adding an excessive amount of fresh lime or other strong chemic agent.

Hardness of water varies according to the amount of lime and magnesia salts present. Distillation of water, heavily charged with these or other salts, yield a product free from them, and is eminently necessary in exceptional cases in which not only these, but sodium and other soluble salts abound in the only obtainable supply. Ordinarily, however, it is too expensive, costing much more than a cent per gallon. Of the salts which render water hard, carbonate of lime is most common. This is kept dissolved by the carbonic acid present, which is driven off by boiling. Boiling, therefore, causes most of the carbonate to become insoluble, and to separate as a precipitate. This portion thus removable is called "temporary hardness." The same result is obtainable by adding water-slaked quicklime in proper amount, estimated according to the degree of temporary hardness. If there be 20 parts of this to 100,000 parts of water (which is more than can well be tolerated for all domestic and industrial purposes), about 11.2 parts of fresh quicklime are required to counteract it. This, the so-called Clark process, can be accomplished rapidly by the aid of

several styles of more or less effective apparatus that agitate and aerify the treated water. Ordinary mechanical filters are also introduced into the process, or water may be allowed to settle in a tank for hours after the quicklime, wetted with four or five times its bulk of water and this still further diluted, is well diffused throughout the entire volume of the hard water. After a day or less of settling, the clear water may be drawn off, or the whole filtered. As above explained, the process reduces the percentage of bacteria and organic matter also, as well as the greater part of the lime (and magnesia) carbonate.

As a check upon the addition of an excess of lime, a solution of silver nitrite is recommended. If a little of this be added to a sample of the treated water and a brown precipitate results, it indicates that no more of the lime solution is needed. For each part of sulphate of lime and magnesia ("permanent hardness"), 2.86 parts of fresh sal-soda are required to counteract it.

Springs and wells are fed from the vast quantity of water, usually very free from bacteria, that is present in permeable ground underlain by impermeable strata. Artesian-well supplies have, in addition, an impermeable stratum overlying the water-bearing strata. This supply is derived from rain and snow precipitated upon and sinking into the earth, perhaps a great distance away, and is termed ground-water. It flows along several feet a day, seeking its level toward streams and bodies of water.[1]

When intercepted by rocky or other barriers which

[1] See *The Am. Jour. of the Med. Sciences*, December, 1890.

are impermeable, or nearly so, it tends to flow out as a spring, which, if favorably situated, is free from bacteria, as the water flows from the ground, because of the slow flow through an immense mass of soil that furnishes the most perfect of filters. If into fine, porous soil, well situated, we drive a perfectly clean tube, water similar to that of a pure spring is obtained. The supply remains free from bacteria so long as they are not introduced by contamination from above. Practically the same result, or nearly as good, can be obtained from a carefully dug well in a favorable spot, yet if a well be not properly curbed, covered, and cared for, dirt and bacteria are certain to enter it, and altogether too often prove the source of disease. Unclean buckets, failure to conduct off overflow (waste) water, filth carried in by rain, wind, general carelessness, and especially nearness of privies, barnyards, and other obvious sources of filth, account for the most frequent unsanitary impurity of well waters, Topographic peculiarities, including flaws in the formation into which the well is sunk, account for some contaminations. All germs of disease ought to and by due care can be prevented from entering.

Wells may be regarded as large pipes surrounding an excavation in water-bearing ground and filled to a varying height with water from this cool source. If only unpiped holes in the ground, they are not hygienically complete. If, then, this pipe, covered on top, has an impervious wall tightly fitting in flawless soil and carried up at the top so that no surface washings can be introduced, unless filtered by at least eight or more feet of fine, close soil,

disease bacteria cannot enter. Then all water, however it may vary chemically because of lime, iron, nitrates, chlorids, or what not else, enters only at the bottom through the perfect filter of the fine soil, and so is practically free from bacteria. The immense majority of observers agree upon this point, although occasionally some one comes forward with a statement to the contrary. An eminent biologist has recently reported finding bacteria in deep-driven well waters, but fails to explain that they, like those found by others under such circumstances, were due to contamination from above. Care should be taken during construction to see that the bottom of a dug well has no flaw of the rock or soil to allow bacteria to enter in that unusual way. The well being dug in a place free from danger of contamination of this sort, attention should be paid to the absolute prevention of direct pollution from the surface, which is the source of infection in almost all the cases in which well water causes typhoid and other water-borne disease.

From the lowest part of the wall of the well-shaft, or at least from eight to ten feet below the surface of the ground, there should be a continuous, water-tight concreted casing, and this should rise from one to three feet above the ground. If concrete pipes, two or three feet in diameter, be employed for the purpose they must be well cemented at the joints and loam carefully rammed in around the pipe up to the level of the joint before setting and fixing the next length, all being supported so as not to settle. The top should be protected by a locked or otherwise fastened cover, asphalted, so as to keep out surface

or other waste water, insects, and other things. Lead should not be employed for the purpose. The ground should be graded so as to slope away from the curb. Pails and buckets are not to be used. If a pump be placed over the shaft, provision should exist for conducting off waste water. It is much better that the pump be away from the well and the small (two-inch) pipe used for the pump-connection be carried through the casing at least several feet below the surface of the ground by a hole tightly cemented or asphalted about its periphery so that it allows no leakage into the well. The pipe may usually with impunity be of lead if the water be quite hard, but well-tinned brass or copper is better. Tin pipe, practically free from lead, could until recently be bought for a little more than 16 cents per pound, and ought to be used more frequently. The common form of iron suction-pump is preferable to the endless chain and wooden pumps which are used over very many wells.

As above indicated, wells which are properly constructed and located many feet away from privies, barnyards, wash-water, and other sources of filth that in no case drain toward the shaft, afford healthful water, preferable to that from rain, storage, or any ordinary surface supply. It is usually from surface wash entering, owing to the lack of an impermeable curb, casing, and cover, that germs of disease enter a well and cause typhoid fever and other water-borne diseases. In this sort of pollution is included filth brought upon the boots of users to the cover of the well or to the ground near it and washed in, as by waste-water entering through a defective cover, or carried

in by rain or by leaching in over the edge with puddle-water or drainings. Water from shallow, unprotected wells, which are not grossly faulty in this regard, is likely to be quite clear and taste better than that from deep waters which contain less oxygen, but which are usually much freer from bacteria. That deep protected wells receive much less of the only slightly changed organic and other chemic constituents of the soil which are carried down by heavy rainfall does not count for much hygienically, for it is particularly putrefactive and specific disease bacteria which cause shallow, unprotected wells to be dangerous.

Palmer of the University of Illinois, in a recent chemical report, has added to our great volume of instructive statistics concerning Illinois and other States, which show the unwholesomeness of water from such mere holes in the ground. He emphasizes the familiar fact that deeper wells in the glacial drift of the prairie regions are much less productive of disease, although the water is often unpalatable, not only because of lack of oxygen but also owing to presence of marsh-gas (due to decomposition of vegetable matters) and perhaps of sulphuretted hydrogen. Iron often adds to the unpleasant taste and appearance of such water, so that the senses are likely to mislead people to prefer an inferior product. This explains the slowness with which the unintelligent learn that it is of paramount importance to guard wells against surface contamination. In prairie regions where the ground lies perfectly level, the house well ought to be a hundred feet away from any privy or other filth, and slops and kitchen waste should be carried far

from the locality of the well. When the ground slopes, it must be borne in mind that water seeks a lower level, hence the well should be so situated that the natural flow of the ground-water current is from the well toward any privy or other source of contamination and not in the reverse direction. The ground must be studied to prevent the location of all three of these near together in one common small basin or sink formed by impermeable underground barriers. Mere vicinity of well and house is not necessarily dangerous if no privy or drain be near, and if no slops or other filth or surface drainage can leak into or upon the ground near by. The writer has made bacteriologic tests of carefully constructed wells adjoining, as also underneath houses with thoroughly cemented cellars, and found the water exceedingly pure and likely to remain so as long as no contamination entered; but it is invariably best to have such a source of drinking-water so situated that any one can always see that no carelessness ever introduces contamination.

Local inspection and survey always furnish the most important means of determining the absence of contaminating influence. The shaft of the well is best examined if illuminated, and when emptied the lowest parts can be inspected and flaws carefully searched for. Chemic and especially bacteriologic tests if repeated several times under varying conditions are of considerable value in this respect. For rough practical purposes an inexpensive test, substituting the lithium test, is afforded by throwing a suitable amount of saprol or some intense anilin red, dissolved in water, upon a neighboring filth pile or

in the kitchen slop-water suspected of polluting the well. Common salt can be made to serve the purpose. Saprol is a low-priced coal-tar disinfectant of a very marked odor and taste suggesting illuminating gas or naphtholin and, if it penetrates to the water of the well, betrays its presence in a sample taken. To the taste it is perceptible when only one part is present in two million parts of water. The odor is evident when twice as much is present in the sample. If none of this substance be detected in the well after liberal application of it to the suspected filth, it is presumably safe to use the water. If saprol enters the well, further and more precise examination should be undertaken to determine the defect. When the water of a well is exposed to pollution which cannot be prevented, and the trouble is not remediable by the introduction of an impervious curbing and the other safeguards above recommended, the safest way is to fill up the well and make a proper new one in a good location. Koch's recommendation to convert a faulty well into a driven well by filling it up with sand and sinking a pipe in it is not practicable in most cases. At any rate, if this expedient be tried, thorough disinfection and cleansing should precede its employment.

In towns and wherever else it is available, steam driven in for two or three hours at a pressure of from two to four atmospheres is an efficient disinfectant. The leather valve of the pump is to be treated apart by soaking it for an hour in a 1 to 1000 solution of corrosive sublimate. After steaming has ceased, the water should remain in the closed well for nearly a day and then be removed together with the dead

frogs and other organic matter which, by subsequent decomposition, would become offensive, as would be the case after the use of lime or other chemicals. One portion of freshly slaked lime thrown in for every fifty parts of water proves an efficient disinfectant. It is cheaper than bromin or permanganate of potash and more satisfactory than the addition of one per cent. of sulphuric acid. Steam acts upon the entire well, while, when chemicals are added to the water, the walls have to be treated in addition. For artesian and other driven wells, Neisser recommends that steam be driven to the bottom of the tube by means of a small pipe sunk nearly to the bottom. Another pipe may also be introduced for the purpose of drawing out the water at the same time.

Ground water derived from carefully located gang wells and used promptly without being stored is usually very free from bacteria and other organic life. This is especially true when the territory which the driven pipes drain is reserved for a park and guarded from contamination. Such sources may in the end prove to yield less than the expected amount. If then, undue suction be employed to augment the flow of water, the results are unsatisfactory, and underground defects and partial stoppages of the pipes may be produced. When locating such a plant, bacteriologic tests are indispensable for preliminary determination of the quality of the water derived through sterile experimental tubes, samples being taken at different stages of the pumping. A chemic examination is also necessary for learning the amount of iron, hardness, chlorids, and organic matter.

Artesian wells usually yield water of great purity

as regards bacteria, yet tests of the water from these deep borings sometimes show numerous bacteria other than those introduced from above ground through carelessness. The character of those found aids in determining their source. There are cases in which various forms of water-life have been carried long distances through coarse strata, and the possibility of contamination from the remote outcrop of the water-bearing strata, must be borne in mind. In those regions in which these deep wells have most frequently been bored, the distant outcrop is usually so situated as to preclude the likelihood of infection entering the water there. Considerable salt occurs in artesian well water in some districts.[1] With all their usual excellence as regards absence of bacteria, deep ground waters, even if the yield continues ample, proves at times too hard and contain too much iron to make them satisfactory, unless they undergo treatment. Moreover, the sieves introduced on the lower end of the driven tubes for the purpose of keeping out sand, tend to become incrusted and thus greatly retard the flow. To remedy this obstruction, hydrochloric acid, diluted with nine times its volume of water, may be carried down to the bottom of the tube through a small pipe, and allowed to exercise its solvent action for nearly fifteen minutes, after which time it is pumped out.

Iron, so common in water from deep wells, may in some cases occur as phosphates of iron in part, but is usually in the form of free ferrocarbonate dis-

[1] An excellent monograph on "The Artesian Wells of Dakota," by Gilbert, is contained in the report xviii, 2d part, of the U.S. Geological Survey.

solved in the carbonic acid of the water. If this be driven off in the presence of air, or, if the iron water merely comes briefly into contact with air, the iron carbonate is thereby changed into insoluble ferric compounds; consequently, according to the amount of iron present, and the length of time that the oxygen of the air has worked, the water becomes opalescent, then gradually yellowish-brown, because of the innumerable minute particles precipitated, and which can be filtered out, leaving the water clear. Earthly alkalies present favor the separation of the iron. Any contrivance, such as a spray or an aërified filter, which causes the water to be exposed to the action of air will remove nearly all of the iron from a water.

Filtration, through from seven to ten feet of pieces of coke, gravel, or broken rock, one millimeter in size, with the utmost possible exposure to air, has been found in German experience to remove iron successfully. The slimy precipitate collects and the upper layer of the filter has to be cleaned every fortnight or so, and the entire mass needs renovating, or renewing every few months. Dunbar[1] has indicated a suitable mechanic sand-filter for use on a small scale. The Krölınke process for removing iron calls for the addition of ten parts of ferrosulphate of iron to one million parts of the iron water. Then from fifty to a hundred parts of lime (with water) are stirred in and the whole allowed to stand for twenty minutes before filtering. Hardness, as well as organic constituents, is also greatly lessened by this process, which at the same time separates most of the bacteria.

[1] *Ztschr. für Hyg.*, xxii, 68.

Steckel's process, used in connection with an ordinary well, consists in packing a layer of lime, or, preferably, tribasic phosphate of lime, on the bottom and sides of the well, and fixing it in place so that the entering ground water passes through the lime, which remains efficient for years without removal. It greatly increases the hardness of the water, but removes iron.

For domestic use a bone-charcoal filter will attract and separate iron, lead, or other metallic impurities, present in small amount in water which flows slowly through it. Even the ordinary carbon cylinders sold for filtering have some value in this way, although it must be remembered that they have the defects of all ordinary filters. If such filters become clogged by the iron slime, they may be renovated by soaking them in dilute hydrochloric acid. If such a filter be used as a makeshift, the cylinder may be covered with coarse sand, and the water aërified by dropping upon it from a height. Whether any of these or a mechanical filter be used for deferrating water, the main thing is to see that abundant exposure to air takes place.

Rain water, being precipitated moisture of the atmosphere, is very pure as regards the presence of lime salts and other things taken up by surface and ground waters. As ordinarily obtained from a roof, through a gutter and pipe, the first portion that falls takes up not only the soot, dust, and grass which may be in the air, especially of cities, but the washings of the roof and gutters as well. It is best that the first portion which falls be allowed to flow off, carrying leaves, bird droppings, and other dirt, the following

portion then proving much purer. Automatic contrivances exist to effect this separation of the unclean first flow, but are not likely to prove popular. They are apt to work badly when leaves or other coarse dirt are washed in. When rain water is of necessity depended upon for a supply, the water-conductor should be kept shifted so that the water running down after rain has begun to fall will be diverted until after the dirt has been washed off, then the following water may very easily be guided into the cistern. In many cases this water contains very many bacteria, which thrive in the darkness and abundant organic matter. Boiling renders it fit to drink. The cisterns or tanks employed to hold water become foul if of wood, and should never have lead in any part, even for piping or cement. Bricks, well coated with hydraulic cement, are approved for cistern construction. Reservoirs of any sort need cleaning from time to time. Chemicals, such as above indicated for porcelain filter-tubes, serve the purpose of disinfecting these also. Steam is excellent when it can be applied.

SUMMARY.

Water may be very clear and palatable, yet at the same time may chance to be impure. As precipitated by condensation of vapor it is pure. Precipitated from the clouds and sinking into the earth's surface and other natural reservoirs it remains wholesome so long as bacteria capable of inducing disease do not enter it. Bacteria present in almost all natural surface waters remote from habitation are presumably harmless. Harmful micro-organisms tend to perish or become innocuous in course of time after entering

ordinary water, yet complex conditions may make the operation of this principle uncertain. If harmful bacteria are known to be present more or less regularly in a given supply, or if the entrance of sewage or other obvious pollution near an intake make its presence probable, it is most necessary to employ adequate filtration or other means of purifying water taken from that place. Distilled water is wholesome if it contain no lead. The receptacles in which this and various originally pure bottled waters are stored and transported are often bacteriologically unclean. Boiling, even for a moment, destroys the causative germs of typhoid fever, cholera, and other diseases known to be likely to occur in polluted waters. Ordinary small filters are usually quite inadequate to hold back disease bacteria or any others. All of them allow bacteria to multiply in the filtering substance and to pass through into the filtered water. Reported cases show that ordinary filters can harbor disease germs and cause disease. Small filters of very dense texture, such as the best porous porcelain and also the material used in the Berkefeld filter, can hold back all micro-organisms and thus yield absolutely sterile water for a limited number of days if intelligently cared for. None of these are permanently "germ-proof."

The only permanently germ-proof filter is the natural one formed by immense quantities of fine porous earth, through which "ground water" slowly flows. Filtration by well-managed large gravity filter-beds of fine sand approximates this natural process in efficiency, being capable of rendering the water practically pure. Mechanical filters can accomplish the same

result, but are less likely to be maintained constantly in a condition of the highest efficiency.

Ground water, uncontaminated, is hygienically pure, under the conditions indicated above. In very many cases it is the best available source of supply. Free from bacteria as it issues from favorable ground, it frequently becomes contaminated because of carelessness. An outlay of effort and of money, usually much less than would be required for securing a pure surface supply, will eliminate the defect, which is commonly a local one. Open, shallow wells, unprotected from direct pollution by surface washings from privies and other filth, are a notorious source of pollution by, and dissemination of, the germs of typhoid fever and other diarrheal diseases, including cholera whenever and wherever that occurs. If properly located, and provided with a continuous watertight casing and curb tightly covered, and if it has a good pump which does not necessitate an aperture above ground, even a shallow well can furnish wholesome water.

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